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(54) **SOLID-STATE IMAGE SENSOR AND IMAGING APPARATUS USING SAME**

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H01L 27/146 (2006.01)
H04N 5/335 (2011.01)
H04N 5/369 (2011.01)

(52) **U.S. Cl.**
CPC ***H04N 5/3696*** (2013.01); ***H01L 27/14601*** (2013.01); ***H01L 27/14627*** (2013.01); ***H04N 5/335*** (2013.01)

(58) **Field of Classification Search**
CPC H04N 5/335; H04N 5/3745; H01L 27/14601; H01L 27/14627
See application file for complete search history.

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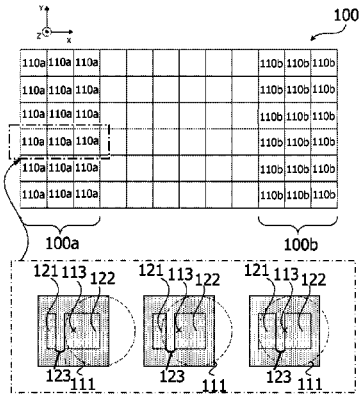
(57) **ABSTRACT**

A solid-state image sensor provided with a plurality of pixels which photo-electrically convert an object image formed by an imaging optical system, wherein at least a portion of the plurality of pixels are ranging pixels in which a first photo-electric conversion unit, a barrier region and a second photo-electric conversion unit are provided in alignment in a first direction in this sequence; in the peripheral regions where are distanced from a straight line perpendicular to the first direction and passing through the center of the solid-state image sensor, for more than half of the ranging pixels, the barrier region is situated eccentrically in a direction parallel to the first direction.

15 Claims, 11 Drawing Sheets



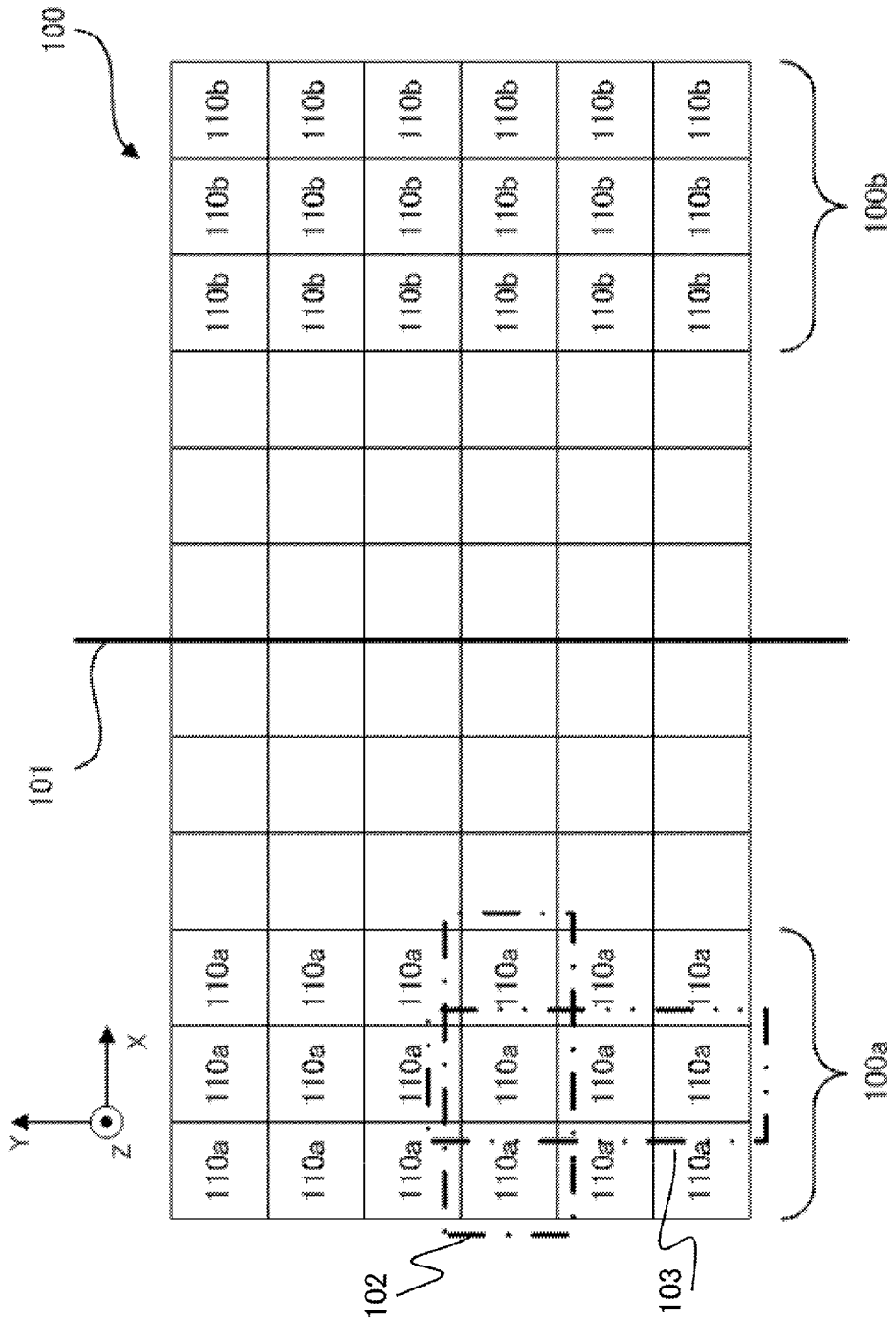


FIG. 1

FIG. 2A

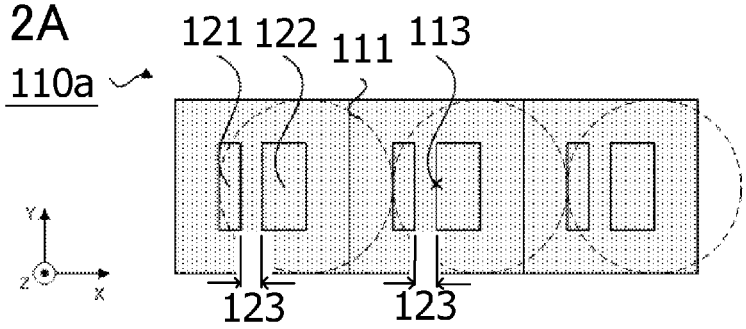


FIG. 2B

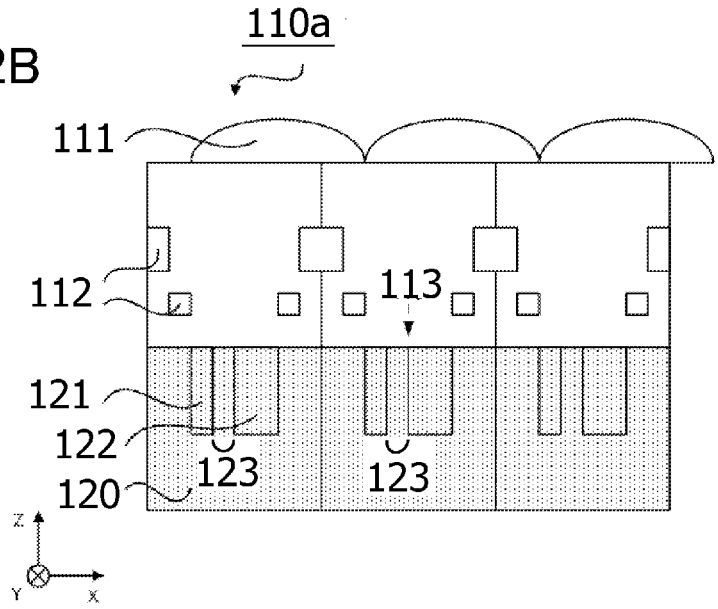


FIG. 2C

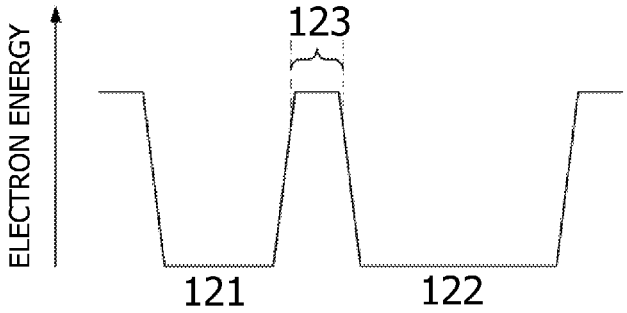


FIG. 3A

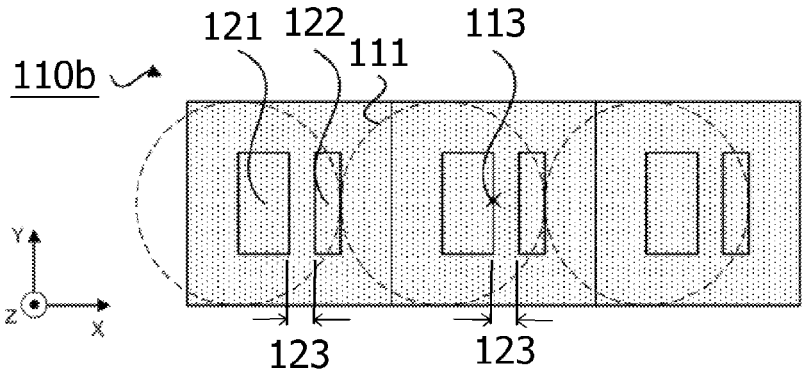

121
122
111
113
110b
Y
Z
X
123
123

FIG. 3B

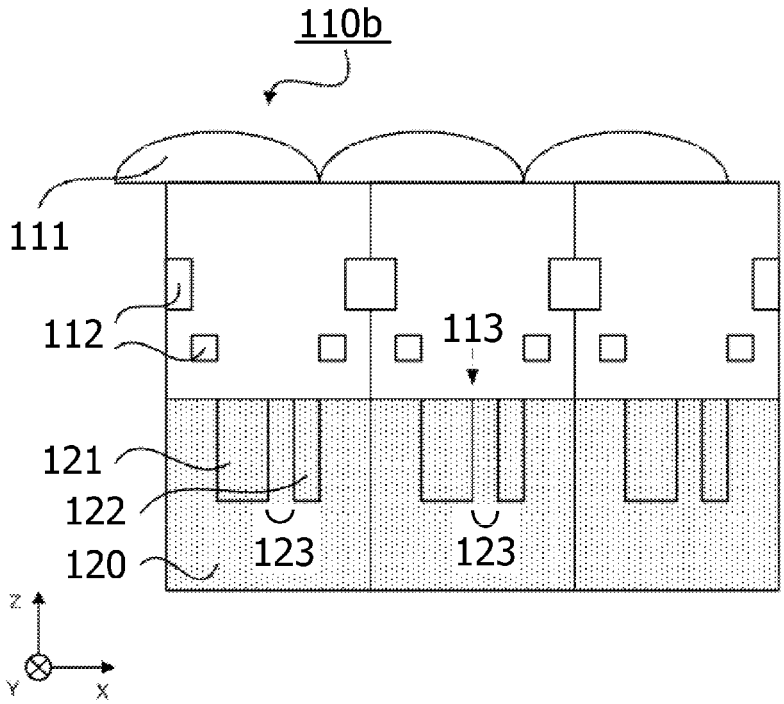

110b
111
112
113
121
122
120
123
123
Z
Y
X

FIG. 4A

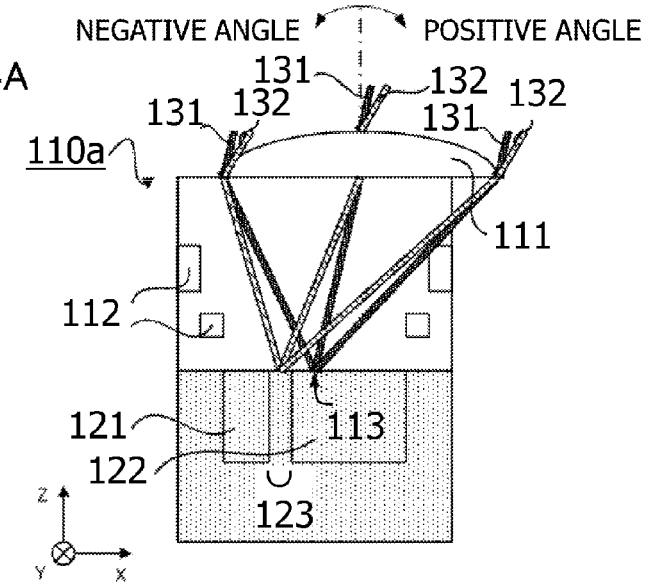


FIG. 4B

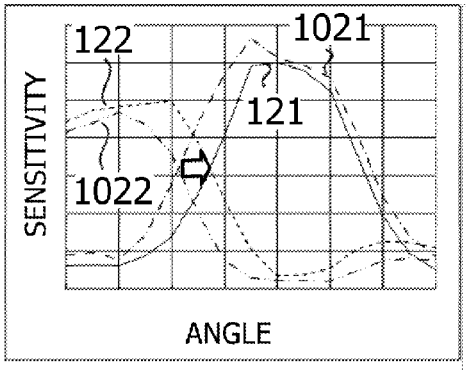
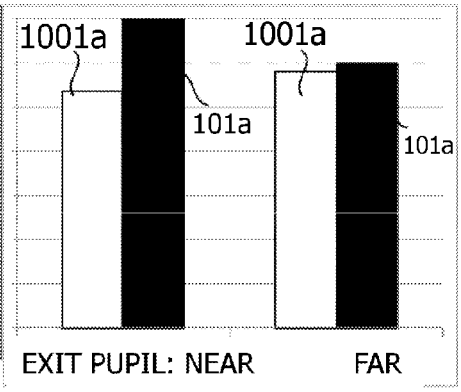


FIG. 4C



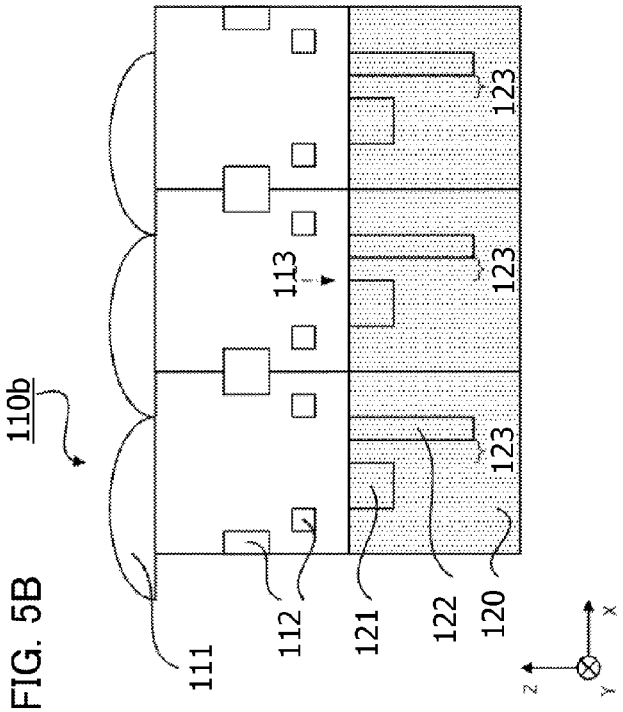

110b
111
112
113
120
121
122
123
123
123
123
X
Z
Y

FIG. 5B

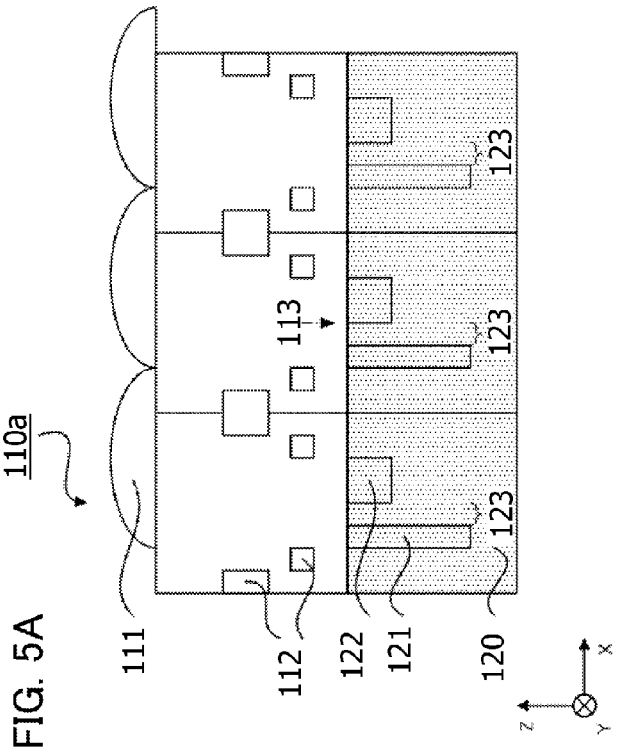

110a
111
112
113
120
121
122
123
123
123
123
X
Z
Y

FIG. 5A

FIG. 6A

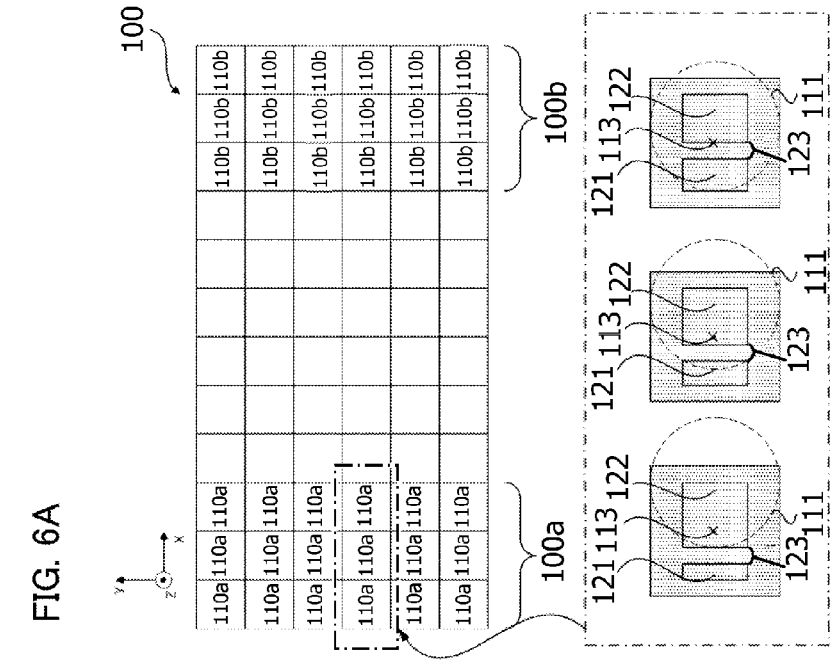

100
100a
100b
110a
110b
111
113
121
122
123

FIG. 6B

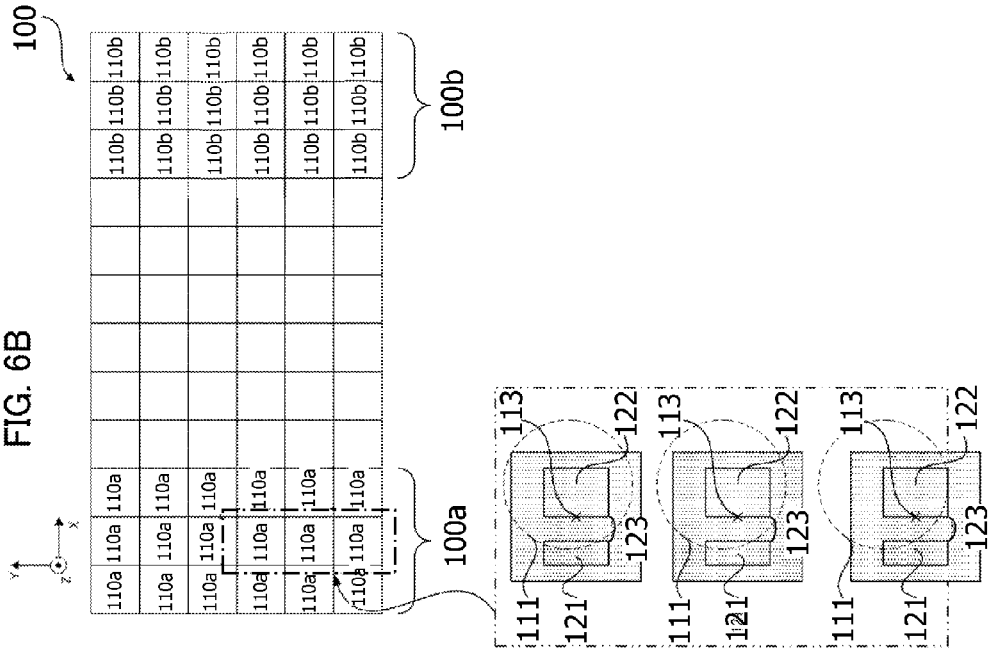

100
100a
100b
110a
110b
111
113
121
122
123

FIG. 7

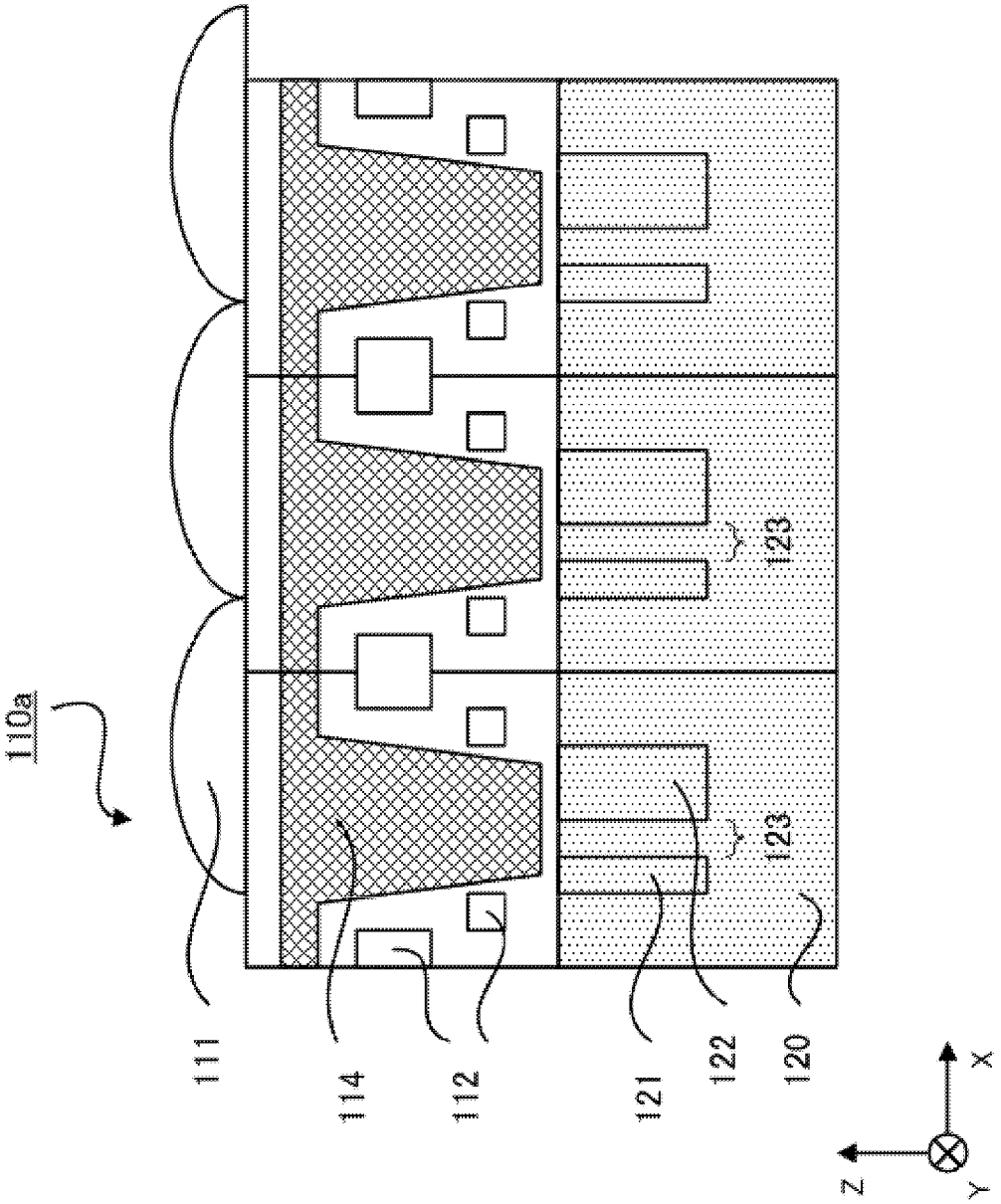


FIG. 8

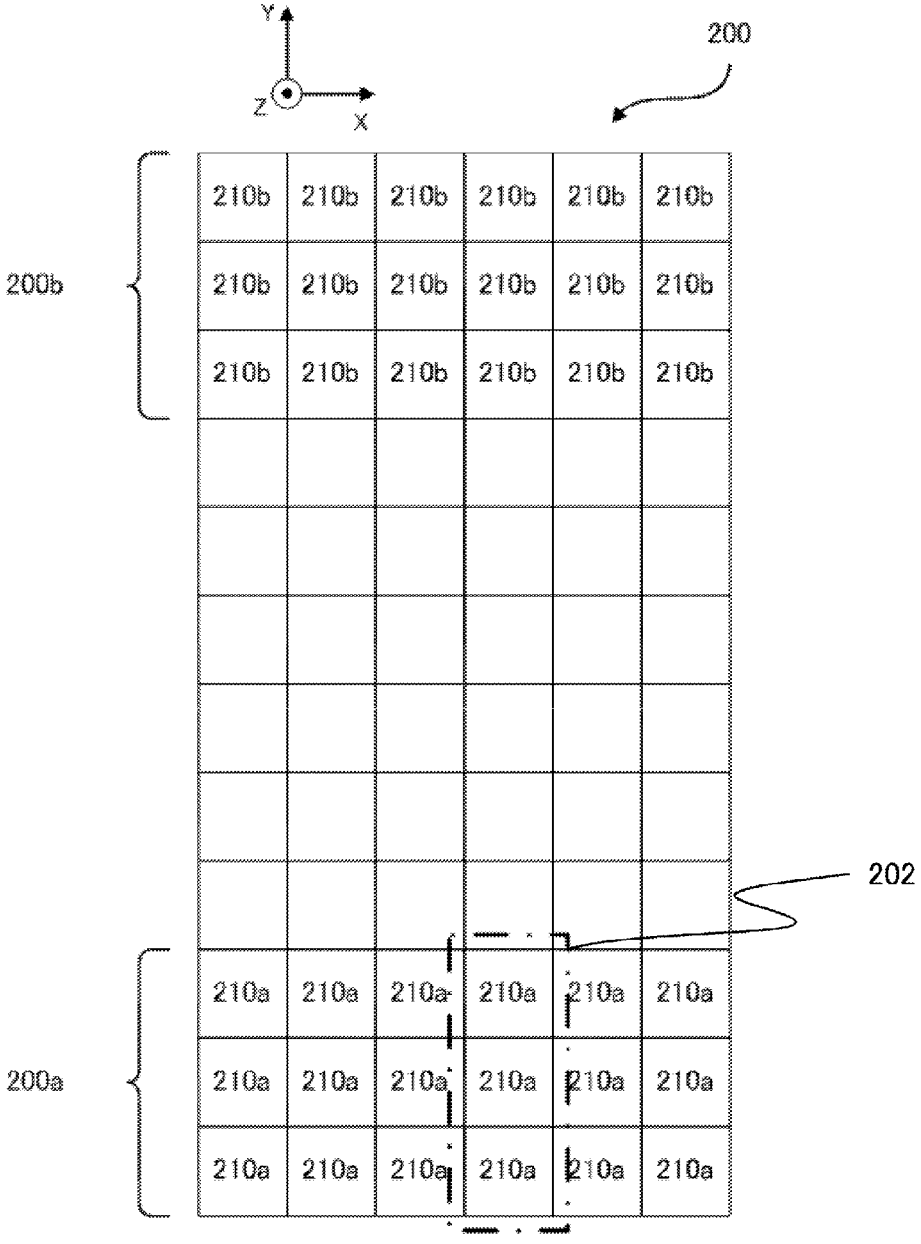


FIG. 9A

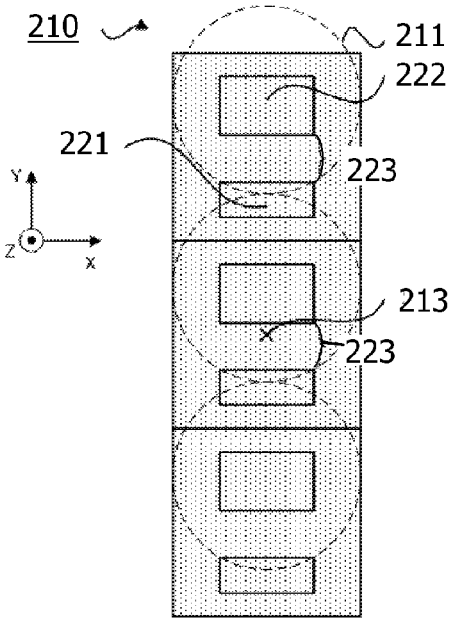

210
211
222
221
223
213
223
Y
Z
X

FIG. 9B

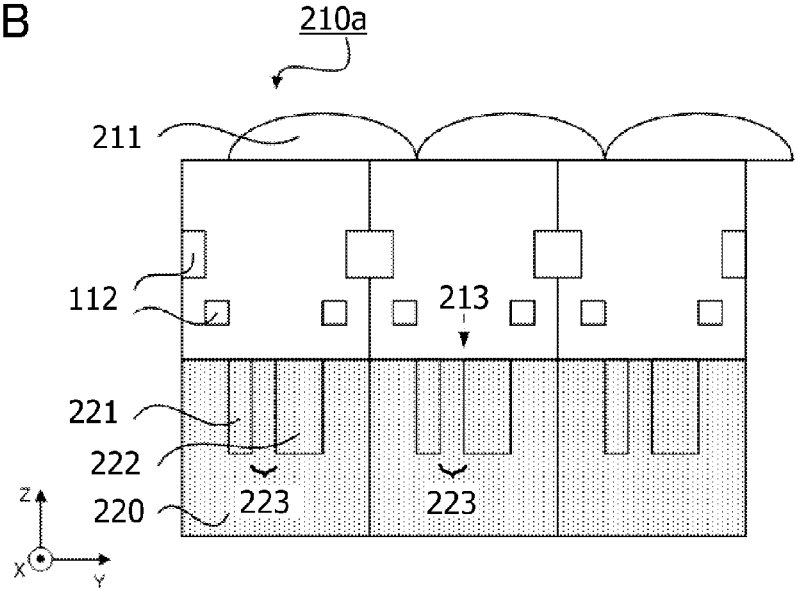

210a
211
112
213
221
222
220
223
223
Z
X
Y

FIG. 10

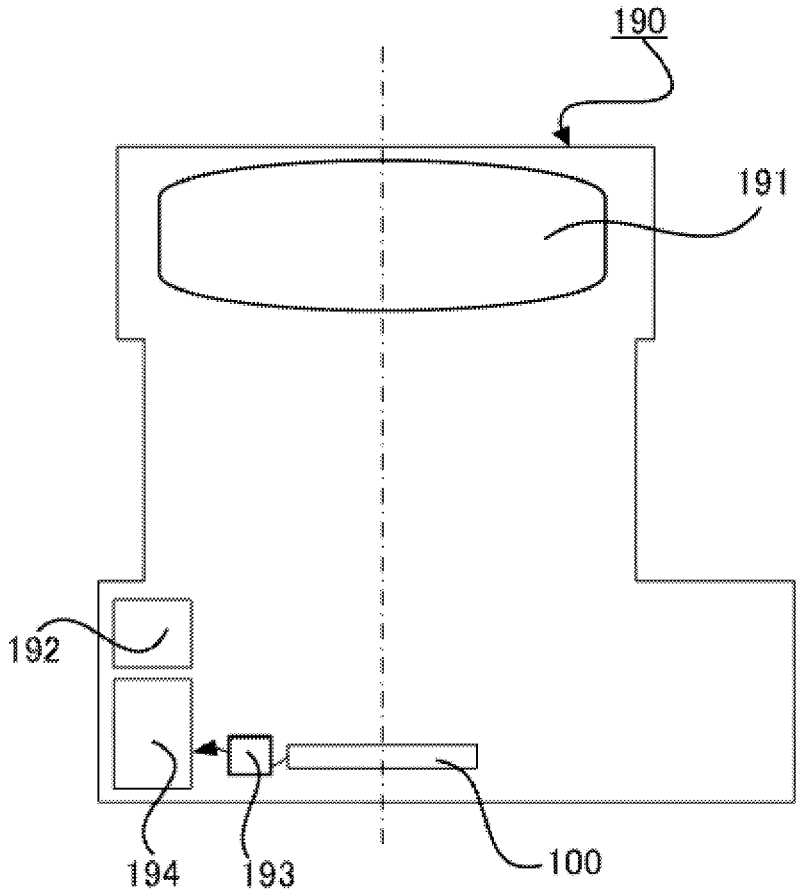


FIG. 11A

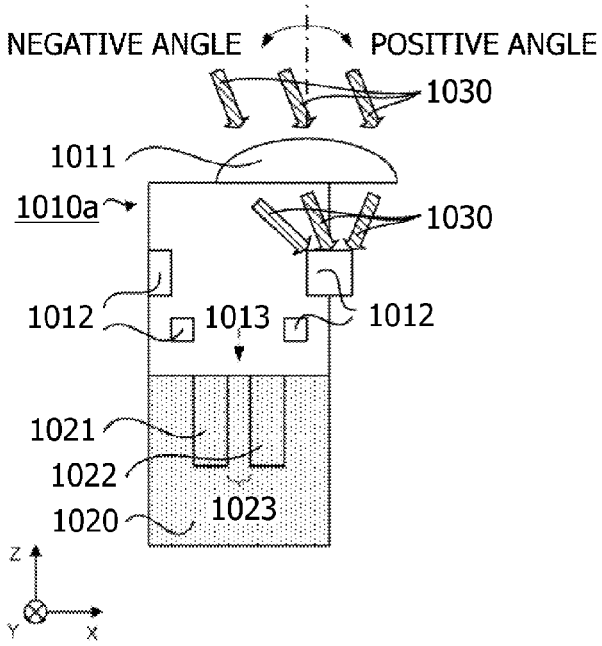


FIG. 11B

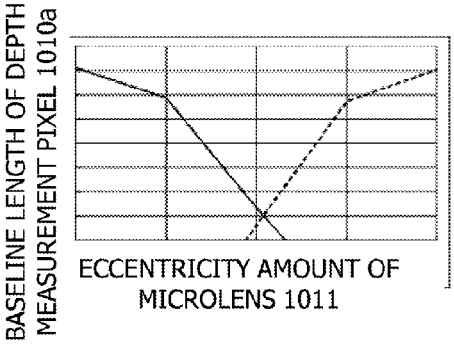
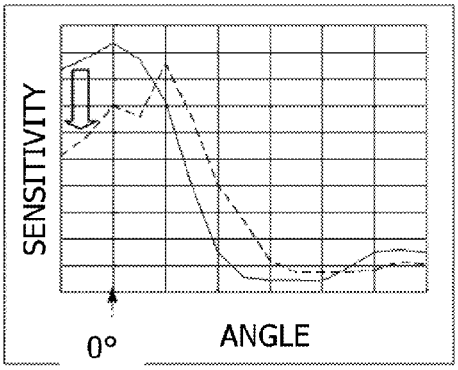


FIG. 11C



SOLID-STATE IMAGE SENSOR AND IMAGING APPARATUS USING SAME

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to a solid-state image sensor, and more particularly, to a solid-state image sensor used in a digital camera or video camera.

2. Description of the Related Art

In recent years, from the viewpoint of making digital cameras more compact in size, a solid-state image sensor which corresponds to a camera lens having a short back focus has been demanded. Furthermore, from the viewpoint of expanding the dynamic range of a digital camera, there have been demands to use a solid-state image sensor having a large size in compact digital cameras. In a digital camera which is subject to requirements of this kind, since the light beam is input at a widely inclined angle to the pixels in the peripheral region of the solid-state image sensor, the sensitivity of the pixels in the peripheral region is reduced.

In view of this problem, Japanese Patent Application Publication No. 2010-182765 discloses a solid-state image sensor in which microlenses provided on pixel surfaces are situated eccentrically with respect to the central direction of the solid-state image sensor, whereby it is possible to detect, with good accuracy, a light beam input at an inclined angle with respect to the pixels.

On the other hand, focal point detection technology is also available in digital cameras. Japanese Patent No. 04835136 discloses, in respect to this technology, a solid-state image sensor which has a composition for focal point detection by a phase differential method in a portion of the pixels of a solid-state image sensor. A phase differential method is a method which compares the images of light passing through different regions of the pupil of an imaging optical system, and detects a depth by triangulation based on the stereo images.

SUMMARY OF THE INVENTION

Even in a solid-state image sensor having a depth measurement function such as that disclosed in Japanese Patent No. 04835136, a problem occurs in that the pixel sensitivity declines in the peripheral portion if the back focus is shortened or the dynamic range is expanded. In order to respond to this problem, it is conceivable to apply a method in which the microlenses are arranged eccentrically toward the center direction of the solid-state image sensor, as disclosed in Japanese Patent Application Publication No. 2010-182765.

However, if the method of eccentric arrangement of the microlenses disclosed in Japanese Patent Application Publication No. 2010-182765 is simply combined with the ranging pixels disclosed in Japanese Patent No. 04835136, then problems such as the following occur. In general, the exit pupil position of the focusing optical system changes with the zoom and focus conditions of the camera lens. Furthermore, in the case of a solid-state image sensor used in a camera compatible with exchangeable lenses, the exit pupil position of the imaging optical system changes with the lens used. In other words, the angle of the main light beam which is incident on the ranging pixel varies with the lens used and the zoom and focus conditions.

Consequently, a trade-off arises in that if the amount of eccentricity of the microlenses is small, then the depth accuracy with a near exit pupil position of the imaging optical system becomes poor, and if the amount of eccentricity of the microlenses becomes large, then the depth accuracy with a far exit pupil position of the imaging optical system becomes poor.

It is an object of the present invention to provide a solid-state image sensor capable of performing highly accurate depth measurement (ranging), irrespective of the lens used and the zoom and focus conditions.

The first aspect of the present invention is a solid-state image sensor provided with a plurality of pixels which photoelectrically convert an object image formed by an imaging optical system, wherein at least a portion of the plurality of pixels are ranging pixels in which a first photoelectric conversion unit, a barrier region and a second photoelectric conversion unit are provided in alignment in a first direction in this sequence; when the region of the solid-state image sensor is divided by a straight line perpendicular to the first direction and passing through the center of the solid-state image sensor, into a first region which is positioned in a negative direction of the first direction from a straight line perpendicular to the first direction, and a second region which is positioned in a positive direction of the first direction from a straight line perpendicular to the first direction; more than half of the ranging pixels in a portion of the first region which is distanced by at least a prescribed distance from the straight line perpendicular to the first direction and passing through the center of the solid-state image sensor are first ranging pixels in which the center of a barrier region is situated eccentrically in the negative direction of the first direction with respect to the center of the ranging pixel; and more than half of the ranging pixels in a portion of the second region which is distanced by at least the prescribed distance from the straight line perpendicular to the first direction and passing through the center of the solid-state image sensor are second ranging pixels in which the center of a barrier region is situated eccentrically in the positive direction of the first direction with respect to the center of the ranging pixel.

According to the present invention, it is possible to carry out highly accurate depth measurement, even in a peripheral portion of a solid-state image sensor, irrespective of the lens used and the zoom and focus conditions.

Further features of the present invention will become apparent from the following description of exemplary embodiments with reference to the attached drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a diagram showing a solid-state image sensor relating to the first embodiment;

FIGS. **2**A to **2**C are diagrams showing ranging pixels relating to the first embodiment;

FIGS. **3**A and **3**B are diagrams showing ranging pixels relating to the first embodiment;

FIGS. **4**A to **4**C are diagrams illustrating the characteristics of a ranging pixel;

FIGS. **5**A and **5**B are diagrams showing modification examples of ranging pixels relating to the first embodiment;

FIGS. **6**A and **6**B are diagrams showing modification examples of ranging pixels relating to the first embodiment;

FIG. **7** is a diagram showing a modification example of a solid-state image sensor relating to the first embodiment;

FIG. **8** is a diagram showing a solid-state image sensor relating to the second embodiment;

FIGS. **9**A and **9**B are diagrams showing ranging pixels relating to the second embodiment;

FIG. **10** is a diagram showing an imaging apparatus relating to the third embodiment; and

FIGS. **11**A to **11**C are diagrams showing ranging pixels according to a comparative example.

DESCRIPTION OF THE EMBODIMENTS

Below, a ranging device according to an embodiment of the present invention will be described. Here, elements which have the same function are labelled with the same reference numerals in all of the drawings, and repeated description is omitted.

First Embodiment

<In-Plane Arrangement>

FIG. **1** is a diagram showing an arrangement of the ranging pixels in a solid-state image sensor **100** according to the present embodiment. First ranging pixels **110***a* are ranging pixels which are arranged in a peripheral region **100***a* in a −X direction (first region) in the solid-state image sensor **100**. The peripheral region **100***a* is a region which is distanced by at least a prescribed distance in the −X direction from a straight line **101** extending in a direction which is perpendicular to the X direction (namely, in the Y direction) and which passes through the center of the solid-state image sensor **100**. On the other hand, second ranging pixels **110***b* are ranging pixels which are arranged in a peripheral region **100***b* in a +X direction (second region) in the solid-state image sensor **100**. The peripheral region **100***b* is a region which is distanced by at least a prescribed distance in the +X direction from a straight line **101** extending in a direction which is perpendicular to the X direction (namely, in the Y direction) and which passes through the center of the solid-state image sensor **100**. The square shapes not labelled with the reference numerals **110***a* and **110***b* may be ranging pixels or may be normal imaging pixels. The ranging pixels and the imaging pixels are described below. The prescribed distance is desirably not less than 0.25 times, and more desirably, not less than 0.40 times, the X-direction length of the solid-state image sensor **100**. The reason for this is as follows.

<Photoelectric Conversion Units and Barrier Region>

FIG. **2** is a diagram showing a composition of three ranging pixels **110***a* which are arranged in a peripheral region **100***a* (first region) of the solid-state image sensor surrounded by the single-dotted line **102** in FIG. **1**. FIG. **2**B is a schematic diagram in the XZ cross-section of three ranging pixels **110***a*. The ranging pixels **110***a* each have, from the side where the light is incident, a microlens **111**, photoelectric conversion units **121**, **122** formed inside the substrate **120**, and a barrier region **123** arranged between the photoelectric conversion units **121**, **122**. FIG. **2**A is a planar schematic drawing of three ranging pixels **110***a* in the XY plane in FIG. **1**. The first photoelectric conversion unit **121**, the barrier region **123** and the second photoelectric conversion unit **122** are arranged in this sequence in the +X direction (the positive direction of the first direction).

As shown in FIGS. **2**A and **2**B, the center of the barrier region **123** of the ranging pixel **110***a* is situated eccentrically (off-centered) in the −X direction (the negative direction of the first direction) with respect to a pixel center **113** of the ranging pixel **110***a*. Here, the pixel center is the center of gravity of the region including the XY cross-section of the photoelectric conversion unit, which is surrounded by the projected portion of a wire **112** surrounding the pixel, when the wire **112** is projected to an XY cross-section on the surface of the substrate.

The photoelectric conversion units **121** and **122** are created by forming a potential distribution by ion doping in the substrate **120** which is made from a material, such as silicon, having absorptivity in the detected wavelength band. A potential barrier is formed between the photoelectric conversion units **121** and **122**, to create a barrier region **123**. The barrier region **123** indicates a region including the maximum value of the potential barrier formed between the photoelectric conversion units **121** and **122** (FIG. **2**C). More specifically, it is a region having a potential barrier size of equal to or more than 90% of the maximum value of the potential barrier.

The size of the potential barrier in the barrier region **123** may be determined by the amount of electric charge cross-talk tolerated between the photoelectric conversion units **121** and **122**. The greater the potential barrier, the greater the extent to which the amount of electric charge cross-talk can be suppressed. Conversely, the smaller the potential barrier, the greater the effective size of the photoelectric conversion region, and the further the extent to which the sensitivity of the ranging pixel can be improved. It is also possible to form a potential barrier by ion doping in the region corresponding to the barrier region **123**, rather than the regions corresponding to the photoelectric conversion units **121** and **122**. Furthermore, it is also possible to perform ion doping in both regions. In this case, desirably, ions having conductivity that is the reverse of the ions doped into the region corresponding to the photoelectric conversion units are doped into the barrier region.

<Micro-Lenses>

The microlenses **111** respectively conduct the light beam in different regions of the exit pupil (not illustrated) of the imaging optical system to the photoelectric conversion units **121** and **122**. The light beam incident on the respective photoelectric conversion units is converted into an electrical signal, and is sent to a signal processing unit (not illustrated) by wiring **112** which is arranged so as to surround the ranging pixel. It is possible to calculate the depth to the object by the principle of triangulation, by determining the amount of positional displacement between the object image which is acquired from the electrical signal converted by the photoelectric conversion unit **121** and the object image which is acquired from the electrical signal converted by the photoelectric conversion unit **122**.

As shown in FIGS. **2**A and **2**B, the light axis of the microlens **111** of each ranging pixel **110***a* is situated eccentrically in the +X direction (the positive direction of the first direction) with respect to the pixel center **113** of the ranging pixel **110***a*. The microlens **111** is situated eccentrically in the ranging pixels **110***a* of the peripheral region **100***a* of the solid-state image sensor **100** for the same reason as in Japanese Patent Application Publication No. 2010-182765.

The microlens **111** is made from silicon oxide or an organic material, or the like, which is transparent in the detected wavelength region, and is arranged so as to span the photoelectric conversion units **121** and **122**. The ranging pixels and the microlenses **111** correspond to each other in a one-to-one relationship. When this condition is met, a portion of the microlens **111** may be arranged on top of an adjacent pixel.

<Second Region on Opposite Side, and Summary of Arrangement>

As shown in FIG. **3**, in the ranging pixels **110***b* arranged in the peripheral region in the +X direction (second region), the center of the barrier region **123** is situated eccentrically in the +X direction (the positive direction of the first direction) with respect to the pixel center **113**. Similarly, the light axis of the microlens **111** is arranged eccentrically in the −X direction (the negative direction of the first direction) with respect to the pixel center **113**.

In other words, in the peripheral region **100***a* in the −X direction (the negative direction of the first direction) from the straight line **101** passing through the center of the solid-state image sensor, the center of the barrier region **123** is situated eccentrically in the −X direction (the negative direction of the first direction) with respect to the pixel center. On the other hand, in the peripheral region **100***b* in the +X direction (the positive direction of the first direction) from the straight line **101** passing through the center of the solid-state image sensor, the center of the barrier region **123** is situated eccentrically in the +X direction (the positive direction of the first direction) with respect to the pixel center.

By composing the ranging pixels **110***a* and **110***b* in this way, in the peripheral regions **100***a* and **100***b* of the solid-state image sensor **100**, it is possible to achieve highly accurate depth measurement (ranging), regardless of the lens used, or the zoom and focus conditions. Below, the reasons for this are explained by comparison with a prior art example in which the center of the barrier region coincides with the pixel center. For the purpose of simplification, only the ranging pixels arranged in the peripheral region in the −X direction are described here, but a similar explanation obviously applies to the ranging pixels arranged in the peripheral region in the +X direction also.

<Description of Prior Art Example and Problems>

FIG. **11**A shows a schematic drawing of a ranging pixel **1010***a* which is arranged in a peripheral direction in the −X direction in a solid-state image sensor **1000** according to a comparative example. The ranging pixel **1010***a* includes, from the side where the light is incident, a microlens **1011**, a plurality of photoelectric conversion units **1021**, **1022**, and a barrier region **1023** arranged between the plurality of photoelectric conversion units. The central axis of the microlens **1011** is situated eccentrically in the +X direction with respect to a pixel center **1013** of the ranging pixel **1010***a*. However, in contrast to the ranging pixel **110***a* described above, the center of the barrier region **1023** coincides with the pixel center **1013**. The arrow in FIG. **11**A indicates the mode of propagation of the light beam. This is described hereinafter.

FIG. **11**B is a diagram illustrating change in the baseline length when the amount of eccentricity of the microlens **1011** is changed in the ranging pixel **1010***a*. The baseline length is a value corresponding to the angular difference between the light beams received by the photoelectric conversion units **1021** and **1022**, and the greater the baseline length, the higher the accuracy of depth measurement that can be achieved. The solid line in FIG. **11**B is the baseline length when the exit pupil distance in the imaging optical system is far (for example, the telescopic side of a zoom lens), and the dotted line in FIG. **11**B is the baseline length when the exit pupil of the imaging optical system is near (for example, the wide-angle side of a zoom lens). As is clear from FIG. **11**B, when the amount of eccentricity of the microlens **1011** is small, the baseline length with a far exit pupil distance is large, but the baseline length with a near exit pupil distance is small. On the other hand, if the amount of eccentricity of the microlens **1011** is large, then the baseline length with a near exit pupil distance is large, but the baseline length with a far exit pupil distance is small. In this way, there is a trade-off between the depth measurement accuracy when the exit pupil is near and when the exit pupil is far.

Next, the reasons why this trade-off occurs will be explained. FIG. **11**A shows a mode of propagation of a light beam when the exit pupil distance is far. When the amount of eccentricity of the microlens **1011** is large, a light beam **1030** which passes through a far-distance exit pupil and is incident on the ranging pixel at a negative angle of incidence is absorbed by a wiring **1012** which is arranged in a central direction (+X direction) of the solid-state image sensor with respect to the ranging pixel. Therefore, the angle of the center of gravity of the light beam received by the photoelectric conversion unit **1022** is displaced to the positive angle side. As a result of this, the difference between the angle of the center of gravity of the light beam received by the photoelectric conversion unit **1021** and the center of gravity of the light beam received by the photoelectric conversion unit **1022** becomes smaller, and the depth measurement accuracy declines. Here, with regard to the positive/negative direction of the angle of incidence of the light beam, as shown in FIG. **11**A, the angle of the light beam incident with an inclination in the peripheral direction of the solid-state image sensor (−X direction) (the clockwise direction with respect to the −Z direction), is taken to be positive.

In actual practice, FIG. **11**C shows the angular characteristics of the sensitivity of the photoelectric conversion unit **1022** in a ranging pixel **1011***a*, when the amount of eccentricity of the microlens **1011** is altered. The solid line in FIG. **11**C shows a case where the amount of eccentricity of the microlens **1011** is small and the dotted line shows a case where the amount of eccentricity of the microlens **1011** is large. From FIG. **11**C, it can be seen that if the amount of eccentricity of the microlens **1011** is large, then the sensitivity of the photoelectric conversion unit **1022** with respect to the light beam incident at a negative angle declines.

In this way, in the ranging pixel **1010***a*, if the amount of eccentricity of the microlens **1011** is raised in order to improve the depth measurement accuracy when the exit pupil distance is near, then a portion of the light beam which is incident when the exit pupil distance is far will be absorbed by the wiring inside the pixel. As a result of this, the difference between the angles of the center of gravity of the light beams received by the photoelectric conversion units **1021**, **1022** becomes smaller, and the depth measurement accuracy with a far exit pupil distance declines. This is the principal reason why the trade-off occurs.

<Beneficial Effects of Applying the Present Invention>

On the other hand, in the ranging pixels **110***a* illustrated in the present invention, the center of the barrier region **123** is situated eccentrically in the −X direction (the negative direction of the first direction) with respect to the pixel center **113**. By adopting a composition of this kind, it is possible to eliminate the trade-off. This is described below.

FIG. **4**A shows a mode of propagation of a light beam **132** which is incident on the center of the barrier region **123** and a light beam **131** which is incident on the pixel center **113**, in a ranging pixel **110***a*. As FIG. **4**A reveals, the angle of incidence of the light beam **132** which is incident on the center of the barrier region **123** is inclined in a positive direction with respect to the angle of incidence of the light beam **131** which is incident on the pixel center **113**. Therefore, by situating the center of the barrier region **123** eccentrically in the −X direction with respect to the pixel center, the sensitivity curve of the photoelectric conversion units **121**, **122** is displaced to the positive angle side. As a result of this, the difference between the centers of gravity of the light beams received by the photoelectric conversion unit **121** and the photoelectric conversion unit **122** when the angle of the main incident light beam is large (when the exit pupil distance is near), becomes large, and therefore the depth measurement accuracy with a near exit pupil distance can be improved.

FIG. **4**B show the actual angular characteristics of a ranging pixel **110***a* compared to the angular characteristics of a ranging pixel **1010***a* in which the center of the barrier region coincides with the pixel center. The solid line indicates the

characteristics of the photoelectric conversion unit **121** in the ranging pixel **110***a* and the dotted line indicates the characteristics of the photoelectric conversion unit **122** in the ranging pixel **110***a*. Furthermore, the single-dotted line indicates the characteristics of the photoelectric conversion unit **1021** in the ranging pixel **1010***a* and the double-dotted line indicates the characteristics of the photoelectric conversion unit **1022** in the ranging pixel **1010***a*. From FIG. **4**B, it can be seen that the sensitivity curve of the ranging pixel **110***a* is displaced in the positive direction of the ranging pixel **1010***a*. In this case, as can be seen from FIG. **4**B, the sensitivity of the photoelectric conversion unit **122** with respect to the light beam which is incident at a negative angle (dotted line) is not reduced compared to the sensitivity of the photoelectric conversion unit **1022** (double-dotted line). Consequently, the depth measurement accuracy of the ranging pixel **110***a* with a far exit pupil distance is not reduced compared to the ranging pixel **1010***a*, and the depth measurement accuracy of the ranging pixel **110***a* with a near exit pupil distance can be improved compared to the ranging pixel **1010***a*.

FIG. **4**C shows the baseline length of the ranging pixel **110***a* and the ranging pixel **1010***a* in cases where the exit pupil distance is far and near. In FIG. **4**C, the white bar graph shows a baseline length of the ranging pixel **1010***a* and the black bar graph shows a baseline length of the ranging pixel **110***a*. From FIG. **4**C, it can be seen that, compared to the ranging pixel **1010***a*, the ranging pixel **110***a* shows virtually no decline in the depth measurement accuracy when the exit pupil distance is far, and can improve the depth measurement accuracy when the exit pupil distance is near.

As described above, in the ranging pixel **110***a*, the depth measurement accuracy when the exit pupil distance is near is improved, without any increase in the amount of eccentricity of the microlens, and therefore the trade-off which occurred with the ranging pixel **1010***a* can be eliminated. Therefore, depth measurement of high accuracy can be achieved, regardless of the camera lens and the zoom and focus conditions.

<Further Results>

Moreover, by adopting the composition of the present invention for the ranging pixel **110***a*, the ranging pixel when projecting an object of low brightness is also improved compared to a case where the conventional ranging pixel **1010***a* is used, which is more desirable. This is described below.

In a conventional ranging pixel **1010***a*, the depth measurement accuracy is improved when the exit pupil distance is near, by increasing the amount of eccentricity of the microlens, and therefore a portion of the light beam is absorbed by the wiring, as described above. As a result of this, the sensitivity of the photoelectric conversion unit **1022** which has relatively lower sensitivity, in particular, declines further, and the depth measurement accuracy with respect to an object of low brightness falls. On the other hand, in the conventional ranging pixel **110***a* according to the present invention, the depth measurement accuracy is improved when the exit pupil distance is near, without increasing the amount of eccentricity of the microlens, and hence there is little reflection or absorption of the light beam by the wiring. Consequently, the sensitivity of the photoelectric conversion unit **122** is greater than the photoelectric conversion unit **1022**, and the depth measurement accuracy with respect to an object of low brightness can be improved. In actual practice, as shown in FIG. **4**B, the sensitivity of the photoelectric conversion unit **122** is greater than the sensitivity of the photoelectric conversion unit **1022**. In this case, the sensitivity of the photoelectric conversion unit **121** is slightly lower than the photoelectric conversion unit **1021**, but since the original sensitivity is relatively higher than the photoelectric conversion unit **122**, the effects on the depth measurement accuracy with respect to an object of low brightness are small. In other words, by adopting the composition of the present invention, the difference in sensitivity between the photoelectric conversion unit **121** and the photoelectric conversion unit **122** is reduced, and therefore the depth measurement accuracy when projecting an object of low brightness can be improved.

<Difference in Capacitance>

In the ranging pixels, it is more desirable if the photoelectric conversion unit **121** and the photoelectric conversion unit **122** have different capacities. More specifically, in the ranging pixels **110***a*, desirably, the capacitance of the photoelectric conversion unit **121** positioned in the −X direction is greater than the photoelectric conversion unit **122** positioned in the +X direction. On the other hand, in the ranging pixels **110***b*, desirably, the capacitance of the photoelectric conversion unit positioned in the +X direction is greater than the photoelectric conversion unit positioned in the −X direction. By adopting this composition, it is possible to improve the depth measurement accuracy when projecting an object of high contrast, in particular. The reasons for this are described below.

As can be seen from FIG. **4**B, in the ranging pixels **110***a*, the maximum value of the sensitivity of the photoelectric conversion unit **121** is greater than the maximum value of the sensitivity of the photoelectric conversion unit **122**. If the exposure time is determined in accordance with the sensitivity of the photoelectric conversion unit **121**, then the amount of light at the photoelectric conversion unit **122** will be insufficient, and if the exposure time is determined in accordance with the sensitivity at the photoelectric conversion unit **122**, then the photoelectric conversion unit **121** is liable to become saturated. Here, if the capacitance of the photoelectric conversion unit **121** is greater than the photoelectric conversion unit **122**, then it is possible to resolve the saturation of the photoelectric conversion unit **121** and the insufficiency of the amount of light in the photoelectric conversion unit **122**.

<Changing the Capacitance>

To make the capacitance of the photoelectric conversion unit larger, the capacitance of the photoelectric conversion unit may be made larger. More specifically, any one of the X-direction width, the Y-direction width, and the Z-direction depth of the photoelectric conversion unit may be made larger. Alternatively, it is also possible to increase the capacitance of the photoelectric conversion unit by raising the density of the impurity with which the photoelectric conversion unit is doped. In the ranging pixel **110***a* in the solid-state image sensor which uses the present invention, it is necessary to situate the center of the barrier region **123** between the photoelectric conversion units **121** and **122** eccentrically towards the side of the photoelectric conversion unit **121** with respect to the pixel center. Therefore, desirably, the capacitance is changed by altering the Z-direction depth or the density of impurity in the photoelectric conversion unit.

FIG. **5** shows one example of a case where the Z-direction depth of the photoelectric conversion unit is changed. FIG. **5**A shows a ranging pixel **110***a* and FIG. **5**B shows a ranging pixel **110***b*. As shown in FIG. **5**A, in the ranging pixels **110***a*, the capacitance of the first photoelectric conversion unit **121** which is positioned in the −X direction is greater than the capacitance of the second photoelectric conversion unit **122** which is positioned in the +X direction. On the other hand, as shown in FIG. **5**B, in the ranging pixels **110***b*, the capacitance of the second photoelectric conversion unit which is positioned in the +X direction is greater than the capacitance of the first photoelectric conversion unit which is positioned in the −X direction.

<Control of Drift Electric Field>

It is even more desirable if the magnitude of the drift electric field in the lateral direction in the photoelectric conversion units which have a relatively large capacitance is made greater than the magnitude of the drift electric field in the photoelectric conversion units which have a relatively small capacitance. The reason for this is that the transfer rate of the electric charge becomes slower, as the capacitance of the photoelectric conversion units becomes larger. By making the magnitude of the drift electric field in the photoelectric conversion units which have a relatively large capacitance greater than the magnitude of the drift electric field in the photoelectric conversion units which have a relatively small capacitance, it is possible to suppress differences in the transfer rate of the electrical charge. In order to increase the magnitude of the drift electric field, a gradient of the impurity distribution may be formed in the lateral direction, by carrying out a plurality of doping actions in a staggered fashion in the lateral direction.

More specifically, in the ranging pixels **110***a*, the magnitude of the drift electric field in the lateral direction in the first photoelectric conversion unit **121** which is positioned in the −X direction is greater than the magnitude of the drift electric field in the lateral direction of the second photoelectric conversion unit **122** which is positioned in the +X direction. On the other hand, in the ranging pixels **110***b*, the magnitude of the drift electric field in the lateral direction in the second photoelectric conversion unit which is positioned in the +X direction is greater than the magnitude of the drift electric field in the lateral direction of the first photoelectric conversion unit which is positioned in the −X direction.

<Definition of Peripheral Region>

The greater the distance of the ranging pixel from the straight line **101** passing through the center of the solid-state image sensor, the greater the dependence of the angle of incidence of the main light beam at the ranging pixel, on the exit pupil distance of the imaging optical system. In particular, in the region which is distanced by not less than 0.25 times the X-direction length of the solid-state image sensor from the straight line **101**, the angle of incidence varies greatly. Moreover, in the region which is distanced by not less than 0.40 times the X-direction length of the solid-state image sensor from the straight line **101**, the angle of incidence varies even more greatly. Therefore, the interval between the straight line **101** and the peripheral regions **100***a*, **100***b* (the prescribed distance) is desirably 0.25 times the X-direction length of the solid-state image sensor and more desirably not less than 0.40 times the X-direction length of the solid-state image sensor.

<Greater Eccentricity Towards Periphery>

Furthermore, desirably, the greater the distance of the ranging pixel from the straight line **101**, the greater the amount of eccentricity of the center of the barrier region **123** with respect to the pixel center **113**. By this composition, it is possible to achieve highly accurate depth measurement, even in cases where the lens or the zoom and focus conditions have changed, regardless of the position of the ranging pixel in the solid-state image sensor. Moreover, it is also possible to increase the amount of eccentricity of the microlens **111**, the greater the distance of the ranging pixel from the straight line **101**.

FIG. **6**A shows one example. FIG. **6**A depicts three ranging pixels **110***a* which are in the region of the single-dotted line **102** in FIG. **1**. In FIG. **6**A, the ranging pixels **110***a* are depicted separately. Furthermore, the sequence of the arrangement of the three ranging pixels **110***a* is the same as the sequence of the arrangement of the three ranging pixels **110***a* in the region of the single-dotted line **102** in FIG. **1**. The ranging pixel **110***a* furthest in the −X direction is the ranging pixel **110***a* furthest from the straight line **101** of the three ranging pixels **110***a*, and the ranging pixel **110***a* furthest in the +X direction is the ranging pixel **110***a* nearest to the straight line **101** of the three ranging pixels **110***a*. In accordance with this, the further the position of the ranging pixel **110***a* towards the −X direction, the greater the amount of eccentricity of the barrier region **123** with respect to the pixel center **113**. Similarly, the amount of eccentricity of the microlens **111** becomes greater, the further the position of the ranging pixel **110***a* in the −X direction.

<Eccentricity Also in the Central Region>

In the region in the vicinity of the center of the solid-state image sensor **100**, in other words, the region less than a prescribed distance from the straight line **101** which is perpendicular to the X direction and passes through the center of the solid-state image sensor **100**, the main light beam incident on the pixel is incident at an angle close to perpendicular at all times, irrespective of the exit pupil distance in the imaging optical system. More specifically, if the distance from the straight line **101** is less than 0.25 times the X-direction length of the solid-state image sensor, then the light is incident at an angle close to perpendicular. Therefore, in the vicinity of the center of the solid-state image sensor, the center of the barrier region **123** does not have to be situated eccentrically with respect to the pixel center **113**.

However, in the region in the vicinity of the center of the solid-state image sensor **100**, the main light beam incident on the pixel is incident at an inclination, even though the angle is close to perpendicular. Consequently, in a region which is less than a prescribed distance from the straight line **101** perpendicular to the X direction and passing through the center of the solid-state image sensor **100**, the center of the barrier region **123** may be situated eccentrically with respect to the pixel center.

<Eccentricity of Microlens>

In FIG. **2** and FIG. **3**, an example is shown in which in the ranging pixels the light axis of the microlens **111** is arranged eccentrically with respect to the pixel center **113**, but the microlens **111** does not have to be arranged eccentrically. Even if the microlens **111** is not situated eccentrically, due to the center of the barrier region **123** being situated eccentrically with respect to the pixel center **113**, the sensitivity curve is displaced to the positive angle side with respect to a case where the center of the barrier region and the pixel center coincide with each other. As a result of this, it is possible to improve the depth measurement accuracy in cases where the exit pupil distance is near. As shown in FIG. **2** and FIG. **3**, the light axis of the microlens **111** is desirably situated eccentrically in the central direction of the solid-state image sensor with respect to the pixel center **113**, since this improves the depth measurement accuracy when the exit pupil distance is near.

Moreover, it is also possible for the light axis of the microlens **111** to be situated eccentrically in an oblique direction with respect to the pixel center **113**. The light beam which is incident on the pixels situated in the peripheral regions **100***a*, **100***b* of the solid-state image sensor **100** is inclined with respect to the center of the solid-state image sensor **100**, and therefore, it is desirable for the light axis of the microlens **111** to be situated eccentrically in an oblique direction towards the center of the solid-state image sensor **100**, since this enables the light beam to be input efficiently. FIG. **6**B shows one example of this composition. FIG. **6**B depicts three ranging pixels which are in the region of the double-dotted line **103** in FIG. **1**. In FIG. **6**B, the ranging pixels **110***a* are depicted

separately. In this way, the direction of eccentricity of the microlenses **111** of the ranging pixels **110***a* can be changed in accordance with the arrangement position of the ranging pixel.

<Tolerance of Pixels not Meeting Conditions>

It is not necessary for the center of the barrier region to be situated eccentrically with respect to the pixel center in all of the ranging pixels **110***a*, **110***b* arranged in the peripheral regions **100***a*, **100***b* of the solid-state image sensor, and the center of the barrier region may be situated eccentrically with respect to the pixel center in a portion of the pixels. However, in order to carry out highly accurate depth measurement regardless of the exit pupil distance, it is necessary for the center of the barrier region to be eccentric in the peripheral direction of the solid-state image sensor with respect to the pixel center, in at least more than half of the ranging pixels. The higher the ratio of the ranging pixels which satisfy the above-mentioned conditions, the higher the accuracy of the depth measurement which can be achieved, and therefore the more desirable. For instance, more desirably, not less than 80% of the ranging pixels satisfy the above-mentioned conditions.

<Ranging Pixels, Imaging Pixels and Merits in Captured Image>

All of the pixels of the solid-state image sensor **100** may be ranging pixels, or only a portion thereof may be ranging pixels, and the remainder may be normal imaging pixels. If all of the pixels are ranging pixels, then it is possible to acquire a captured image by taking the sum of the electrical signals acquired by the plurality of photoelectric conversion units. The imaging pixels are images having a single photoelectric conversion unit and a microlens which is arranged on top of the single photoelectric conversion unit.

If a portion of the pixels of the solid-state image sensor **100** are ranging pixels, then the captured image in the ranging pixels may be acquired by the method described above, or may be acquired by complementing with captured images acquired by normal imaging pixels provided about the periphery of the ranging pixel. In the imaging pixels positioned in the peripheral regions **100***a*, **100***b*, it is desirable in order to improve the quality of the captured image for the microlenses to be situated eccentrically in the central direction of the solid-state image sensor.

As described above, by adopting the ranging pixels **110***a*, **110***b* for the composition according to the present invention, the sensitivity difference between the photoelectric conversion units is reduced compared to a case where conventional ranging pixels are used. Therefore, if a ranging pixel image is acquired by summing the electrical signals of a plurality of photoelectric conversion units in the ranging pixels, this is more desirable in terms of improving the quality of the captured image than a case where a conventional ranging pixel is used.

<Waveguide>

It is also possible to provide a color filter between the microlens **111** and the substrate **120**, so as to be able to acquire color information. Furthermore, as shown in FIG. **7**, a waveguide **114** for guiding the light beam efficiently to the photoelectric conversion units **121**, **122** may be provided between the microlens **111** and the substrate **120**. In this case, the waveguide **114** is desirably provided so as to span the photoelectric conversion units **121** and **122**.

<Wiring on Incident Side of Light>

Furthermore, the description given above related to a front surface irradiation type of configuration having wiring on the side where the light is incident with respect to the photoelectric conversion units, but the present invention can also be applied to a rear surface irradiation type of solid-state image sensor having wiring on the opposite side to the side where the light is incident. In a rare surface irradiation type of solid-state image sensor, if the depth measurement accuracy is improved when the exit pupil distance is near by increasing the amount of eccentricity of the microlens, then a portion of the light beam is absorbed by the light shielding portion in order to prevent cross-talk with the adjacent pixels. By applying the present invention, since the amount of absorptivity of the light beam in the light shielding portion is reduced, then it is possible to achieve highly accurate depth measurement, irrespective of the exit pupil distance.

In general, since the wiring is larger than the light shielding portion, then the amount of absorption of the light beam when the amount of eccentricity of the microlens is increased is large. Therefore, the beneficial effects of the present invention become greater when applied to a front surface irradiation type of solid-state image sensor which has wiring on the side where the light is incident, with respect to the photoelectric conversion units.

Second Embodiment

In the ranging pixels in the solid-state image sensor illustrated in the first embodiment, the direction in which the first photoelectric conversion units and the second photoelectric conversion units are aligned is the X direction. In other words, the solid-state image sensor described carries out depth measurement by acquiring light beams incident on the ranging pixels, in a divided fashion in the X direction. However, the present invention can also be applied to a solid-state image sensor having ranging pixels in which the direction of incidence is divided in a direction other than the X direction. FIG. **8** shows one portion of a solid-state image sensor **200** according to the present embodiment.

In this solid-state image sensor **200**, a ranging pixels **210** which perform depth measurement are arranged in such a manner that the incident light beams are divided in the Y direction. The ranging pixels **210***a* are arranged in the peripheral region **200***a* in the −Y direction of the solid-state image sensor **200**. Furthermore, the ranging pixels **210***b* are arranged in the peripheral region **200***b* in the +Y direction of the solid-state image sensor **200**.

FIG. **9** is a diagram showing a composition of three ranging pixels **210***a* surrounded by the single-dotted line **202** in FIG. **8**. FIG. **9**B is a schematic diagram in the YZ cross-section of three ranging pixels **210***a*. The ranging pixels **210***a* include, from the side where the light is incident, a microlens **211**, a first photoelectric conversion unit **221** arranged in order along the +Y direction (the positive direction of the first direction) formed in the substrate **120**, a barrier region **223** and a second photoelectric conversion unit **222**. FIG. **9**A is a planar schematic diagram in the XY direction of three ranging pixels **210**.

The light axis of the microlens **211** of each ranging pixel **210***a* is situated eccentrically in the +Y direction (the positive direction of the first direction) with respect to a pixel center **213** of the ranging pixel **210***a*. The center of the barrier region **223** of each ranging pixel **210***a* is situated eccentrically in the −Y direction (the negative direction of the first direction) with respect to the pixel center **213** of the ranging pixel **210***a*. According to this composition, similarly to the first embodiment, it is possible to improve the depth measurement accuracy when the exit pupil distance is near, without increasing the amount of eccentricity of the microlens. As a result of this, depth measurement of high accuracy can be achieved, regardless of the camera lens and the zoom and focus conditions.

The solid-state image sensor may be composed so as to include both ranging pixels in which the incident light beams are divided in the X direction and ranging pixels in which the incident light beams are divided in the Y direction. By adopting a configuration of this kind, it is possible to carry out depth measurement, regardless of the direction of the contrast in the object. In this case, the direction of eccentricity of the barrier region and the amount of eccentricity may be specified by the direction in which the incident light beams are divided and the position among the ranging pixels of the solid-state image sensor.

The various specific configurations described in the first embodiment can be adopted for the ranging pixels in which the direction of incidence is divided in a direction other than the X direction. Since the composition evidently changes with change in the direction of division, detailed description thereof is omitted here.

Third Embodiment

FIG. **10** is a schematic drawing of an imaging apparatus **190**, such as a digital still camera or digital video camera, provided with a solid-state image sensor **100** shown in the first embodiment. The imaging apparatus **190** includes, in addition to the solid-state image sensor **100**, an imaging optical system **191**, a CPU **192**, a transfer circuit **193**, and a signal processing unit **194**, which are arranged from the side where the light is incident in the solid-state image sensor. The CPU **192** controls the operation of the transfer circuit **193** and the signal processing unit **194**. The signals acquired by the photoelectric conversion units **121** and **122** are transferred to the signal processing unit **194** by the transfer circuit **193**, depth measurement images are formed by the signal processing unit **194**, and depth measurement is carried out by comparing the depth measurement images in the signal processing unit **194**. Furthermore, the signals acquired by the photoelectric conversion units **121**, **122** are similarly processed by the signal processing unit **194**, and are also used as signals for a captured image.

The imaging apparatus **190** may be composed to include the solid-state image sensor **200** shown in the second embodiment.

While the present invention has been described with reference to exemplary embodiments, it is to be understood that the invention is not limited to the disclosed exemplary embodiments. The scope of the following claims is to be accorded the broadest interpretation so as to encompass all such modifications and equivalent structures and functions.

This application claims the benefit of Japanese Patent Application No. 2013-145559, filed on Jul. 11, 2013, Japanese Patent Application No. 2013-183017, filed on Sep. 4, 2013, Japanese Patent Application No. 2014-97073, filed on May 8, 2014, and Japanese Patent Application No. 2014-97074, filed on May 8, 2014, which are hereby incorporated by reference herein in their entirety.

What is claimed is:

1. A solid-state image sensor provided with a plurality of pixels which photo-electrically convert an object image formed by an imaging optical system,

wherein at least a portion of the plurality of pixels are pixels for ranging in which a first photoelectric conversion unit, a barrier region and a second photoelectric conversion unit are provided in alignment in a first direction in this sequence;

wherein when the region of the solid-state image sensor is divided by a straight line perpendicular to the first direction and passing through the center of the solid-state image sensor, into a first region which is positioned in a negative direction of the first direction from the straight line, and a second region which is positioned in a positive direction of the first direction from the straight line:

more than half of the pixels for ranging in a portion of the first region which is distanced by at least a prescribed distance from the straight are first pixels in which the center of a barrier region is situated eccentrically in the negative direction of the first direction with respect to the center of the pixel, and

more than half of the pixels for ranging in a portion of the second region which is distanced by at least the prescribed distance from the straight line are second pixels in which the center of a barrier region is situated eccentrically in the positive direction of the first direction with respect to the center of the pixel; and

wherein a center of a pixel for ranging is a center of gravity of a region defined by the first photoelectric conversion unit and the second photoelectric conversion unit.

2. The solid-state image sensor according to claim **1**, wherein more than half of the pixels for ranging in the first region are first pixels, and more than half of the pixels for ranging in the second region are second pixels.

3. The solid-state image sensor according to claim **2**, wherein,

in more than half of the pixels for ranging in a region of the first region which is less than the predetermined distance from the straight line, the center of the barrier region coincides with the center of the pixel; and

in more than half of the pixels for ranging in a region of the second region which is less than the predetermined distance from the straight line, the center of the barrier region coincides with the center of the pixel.

4. The solid-state image sensor according to claim **2**, wherein the predetermined distance is not less than 0.25 times the length of the solid-state image sensor in the first direction.

5. The solid-state image sensor according to claim **2**, wherein the predetermined distance is not less than 0.40 times the length of the solid-state image sensor in the first direction.

6. The solid-state image sensor according to claim **1**, wherein an amount of eccentricity of the center of the barrier region with respect to the pixel center becomes larger as the distance of the pixel from the straight line gradually increases.

7. The solid-state image sensor according to claim **1**, wherein

the pixels for ranging have a microlens;

a light axis of the microlens in the first pixels in the first region is situated eccentrically in the positive direction of the first direction with respect to the pixel center; and

a light axis of the microlens in the second pixels in the second region is situated eccentrically in the negative direction of the first direction with respect to the pixel center.

8. The solid-state image sensor according to claim **1**, wherein

in the first pixels in the first region, the capacitance of the first photoelectric conversion unit is greater than the capacitance of the second photoelectric conversion unit; and

in the second pixels in the second region, the capacitance of the second photoelectric conversion unit is greater than the capacitance of the first photoelectric conversion unit.

9. The solid-state image sensor according to claim **8**, wherein there is a difference in the capacities of the first and second photoelectric conversion units, due to the depth of the

photoelectric conversion unit being different between the first and second photoelectric conversion units.

10. The solid-state image sensor according to claim **8**, wherein there is a difference in the capacities of the first and second photoelectric conversion units due to the first and second photoelectric conversion units having different impurity densities therein.

11. The solid-state image sensor according to claim **8**, wherein

in the first pixels in the first region, a magnitude of a drift electric field in the first photoelectric conversion unit is greater than a magnitude of a drift electric field in the second photoelectric conversion unit; and

in the second pixels in the second region, a magnitude of a drift electric field in the second photoelectric conversion unit is greater than a magnitude of a drift electric field in the first photoelectric conversion unit.

12. The solid-state image sensor according to claim **1**, wherein the pixels for ranging have a waveguide spanning the first photoelectric conversion unit and the second photoelectric conversion unit.

13. The solid-state image sensor according to claim **1**, wherein the pixels for ranging have a wiring at a position further toward a side where the light is incident than the first photoelectric conversion unit and the second photoelectric conversion unit.

14. An imaging apparatus, comprising:

the solid-state image sensor according to claim **1**; and

an imaging optical system arranged on the side where the light is incident with respect to the solid-state image sensor.

15. The solid-state image sensor according to claim **1**, wherein the center of the pixel for ranging is a center of gravity of a region surrounded by a portion that a wire is projected.

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